BIO – OPTICAL PROGRAMME

CRUISE REPORT

BEAGLE 2003 EXPEDITION

R/V MIRAI

LEG 5: Cape Town, South Africa –

Fremantle, Australia

9th December 2003 – 24th January 2004

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INTRODUCTION

The Blue EArth GLobal Expedition 2003 "BEAGLE 2003" is an Oceanographic research Programme, which was developed by the Japan Marine Science and Technology Centre (JAMSTEC). The objectives of the cruise were three fold: i) to detect and quantify temporal changes in the Antarctic Overturn System corresponding to the global ocean and Southern Ocean warming during this century through high quality and spatially dense observation along old WHP (World Ocean Circulation Experiment Hydrographic Programme: 1991-2002) lines. ii) To estimate the amount of anthropogenic carbon uptake by the Antarctica Ocean; and iii) to provide a training environment in which trainees could get a hands-on experience in collecting bio-optical data. As one of the POGO Trainees, my responsibility was to participate and learn a number of bio-optical measurements as well as providing a helping hand to JAMSTEC's sampling Programme. In this report, I will highlight my learning experience and give some preliminary results.

LEARNING EXPERIENCE

JAMSTEC Programme

The RV Mirai is a big and modern ship; the largest class research vessel in the world. It is designed to carry out a variety of oceanographic research in the World's Oceans, even under severe ocean conditions. During Leg 5 of the BEAGLE cruise, which commenced in Cape Town, South Africa, and ended in Fremantle, Australia (Figure 1), from 9th December 2003 to 24th January 2004, the following observation were carried out:

- Measurements of temperature, salinity, oxygen, current profile, fluorescence and transmission using CTD/O_2 with LADCP, fluorescence meter and transmission meter;
- RMS water sampling and analysis of salinity, oxygen, nutrients, CFC11, 12, 113, SF_6, total alkalinity, dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) and pH;
- Sample water collection for ^{14}C, ^{13}C and $^{3}He/^{4}He$;
- Measurements of autotrophic biomass (epifluorescence and chlorophyll a) by surface LV;
- Bio-optical measurements;
- Underway measurements of pCO_2, temperature, salinity, nutrients, N_2O, surface current, bathymetry, and meteorological parameters; and
- ARGO floats deployment

Most of the measurements involved taking water from the CTD (Fig. 2). We (trainees) received training on how to take samples, from the CTD, for analysis of dissolved oxygen, salinity, nutrients, CFCs, total alkalinity, dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) and ^{14}C. We worked for a shift of 12 hours, and my shift was from 0300 to 1500 hours. It was a good experience on how to be careful when taking samples, especially those that should not have air bubbles. I participated in this sampling from 13th to 26th December 2003; then had to concentrate on bio-optical

measurements only because one of the trainees got sick and had to disembark early (at Port Louis, Mauritius, on 27th December 2003).

Bio-Optical Programme:

The objectives of this programme was, first, to generate a database of bio-optical measurements and primary production from the under-sampled Southern Ocean; and second, to provide a training environment in which trainees could get a hands-on experience in collecting phytoplankton related samples and bio-optical data. In Leg 5, the Bio-optical specialist was Ms. Prudence Bonham, while the trainees were Benjamin Wigley and myself. However, some participants in the JAMSTEC Programme were interested in this Programme, and provided some help. These are Jean Mwicigi, Antonio Mubango and John Bemiasa (the three disembarked at Port Louis, Mauritius); and Andrew Forbes (who assisted us from Port Louis, Mauritius to Fremantle, Australia).

Briefly, we conducted a number of measurements, as outlined below (details of the methods were provided to us before we came for the cruise; furthermore, these protocols can be found in the URL of IOCCG, which is http://www.ioccg.org/training/pogo_ioccg/protocols.html). For the bio-optical daily sampling, water was collected from two Niskin bottles, taken at about 5 m. In addition, one bottle from the depth of fluorescence maximum was sampled for only chlorophyll-a determination. Sampling and analysis were conducted at one or two stations, depending on the timing of the CTD casts. However, solar light measurements were made once a day, close to noon. During too-deep CTD casts, there were no enough Niskin bottles to cover the JAMSTEC as well as bio-optical water requirements. In such cases, water-sample for our procedures was collected at the surface, using a bucket. We needed approximately 20 litres.

Primary production, Picoplankton, Pigments and Coloured materials

1. *PI experiments using ^{13}C mass isotope:* We used artificial light temperature-controlled incubator. Samples were inoculated with ^{13}C and incubated for three hours into 42 light bottles and three dark bottles (polycarbonate, capacity 150 ml). At the end of incubation, they were filtered onto pre-combusted GF/F filters, dried and stored onboard, for later analysis using a mass spectrometer. Irradiance at each of the 42 light bottles was measured using a Biospherical Instrument 4π collector, light meter.

2. *Coloured Dissolved Organic Matter (CDOM)***:** Water sample was filtered through a 47-mm 0.2μ polycarbonate filter and the filtrate was used for determination of CDOM, which was measured from 750 to 250 nm, in 10-cm quartz cell/cuvette using a CARY Model 50 BIO UV/VIS Spectrophotometer. The blank for this sample was Milli-Q water.

3. *Absorption Spectra***:** Duplicate water samples, volume usually 1.5 liters, were filtered on to pre-combusted 25-mm GF/F glass fiber filters. One sample was frozen in liquid nitrogen then stored at –80˚C, for later analysis in Canada. The second sample was analyzed onboard, using the same CARY spectrophotometer,

against a blank through which 25 ml of pre-filtered seawater was passed. Detritus sample was measured after extraction with methanol, against a blank treated in the same way.

4. *HPLC*: Duplicates from each water sample, volume always 1.5 liters, were filtered on to pre-combusted 25-mm GF/F filters. Samples were frozen in liquid nitrogen then stored at –80˚C. They will be analyzed later, using High Performance Liquid Chromatography (HPLC) in the laboratory.

5. *Turner chlorophylls*: Triplicate samples of 100 ml from each sample were filtered on to 25-mm GF/F. Samples were collected from the surface and at the depth of the fluorescence maximum. Chlorophyll-a was extracted in to 10 ml of 95% acetone in the freezer for 24 hours. Chlorophyll-a concentration was measured using a Turner Design 10 AU fluorometer. Phaeopigments were determined after acidification with 1N HCl.

6. *Pico-plankton Counts:* Duplicate samples (1.8 ml) from each water sample were fixed with 0.2 ml paraformaldehyde and then frozen in liquid nitrogen. They were stored at -80˚C, for later analysis in the laboratory.

Solar Light (Optical) Measurements

1. *SIMBADA:* Simbada-21 is an above-water radiometer, which measures water-leaving radiance and aerosol optical thickness in 11 spectral bands. It has an inbuilt GPS antennae that must find at least 3 satellites before measurements are taken. Measurements have to be made in the following sequence: 1 Dark, 3 Sun, 6 Sea, then again 3 Sun and finally 1 Dark.

2. *Hyperspectral Radiometer:* This measures complete spectrum from 350 to 1000 nm, at 0.5 nm intervals. It has a fibre optic that collects irradiance from the sky and the sea. A spectralon, which diffuses incident irradiance, measures the downwelling irradiance.

3. *Photosynthesis Active Radiation (PAR):* The sensor for this instrument is mounted outside, above the Atmospheric Observation laboratory. Hourly averages are recorded, and data were downloaded at the end of the Leg 5-cruise.

Overall, I was familiar with some of the measurements/procedures. However, others were completely new to me. These include: Determination of CDOM, the Simbada-21 and the Hyperspectral radiometer (Figure 3). Furthermore, although I am familiar with PI experiments, this was the first time I have used ^{13}C. Thus, it would be interesting to know the next step of how to compute the amount of carbon fixed from the results of the mass spectrometer. It was very rewarding to learn all the new techniques and corresponding equipment.

PRELIMINARY RESULTS

General Observation

Leg 5 of the BEAGLE Programme crossed the Southern Indian Ocean, along the Latitude 20^0 (Figure 1). Because of low chlorophyll concentration in the water, the Ocean was always blue (Figure 4a) under clear skies and turned "gray" under overcast conditions. However, close to the coast of Australia, where chlorophyll concentration was relatively high, the waters were green in colour (Figure 4b). The wind speed was relatively low, always around 4 to 8 ms^{-1}; white caps were not a common occurrence, although sometimes they were frequent. The swell height also ranged from 0.3 to 2.5m, but mostly it was around 0.5 to 1 m. The water temperatures were higher relative to that of Leg4; it ranged from 24.2 to 28^0C. Higher temperatures occurred in December 2003 and beginning of January 2004; it was slightly lower from 5th January 2004 onwards. With exception of the coastal stations, this Leg covered oligotrophic waters, with very low phytoplankton (chlorophyll a concentration) and probably dominated by very small cells. In total, we conducted 50 sets of bio-optical measurements.

The following sections briefly give some of the preliminary results that could be sub-processed on board. Other results are awaiting analysis in the laboratory, in selected countries (Australia, Canada, Chile and South Africa)

Chlorophyll concentration and Particulate Absorption

Surface chlorophyll-*a* concentration was very low; most of the values were below 0.05 mg m-3. The chlorophyll-*a* concentration ranged from 0.016 to 0.142, with an average of 0.037 mg m-3 (Figure 5). Relatively high values were only observed close to the coast of South Africa, Madagascar and that of Australia (concentration greater than 0.05 mg m-3; Figure 5). Owing to such low concentration of chlorophyll-*a*, the resultant absorption spectra of phytoplankton were noisy, despite filtering 1.5 litres of water and taking 10 spectra of each for averaging (for example, Fig. 6a). The shapes, and in most cases the magnitudes, of the total particulate absorption and phytoplankton absorption were always similar, suggesting that there was less detrital materials in these waters (see e.g., Figure 6b). Thus, these are case 1 waters, where light absorption by particulate matters is dominated by phytoplankton, albeit of low concentration.

It is also assumed that picoplanktonic cells, which easily pass through the GF/F filter, dominate the waters. This is further supported by high values of specific absorption coefficient of phytoplankton, which ranged from 0.053 to 0.294, with an average of 0.181 $(mg\ chl\text{-}a)^{-1}$. About 50% of the total data, mostly those from the "blue" waters, had values above 0.2 m^2 $(mg\ chl\text{-}a)^{-1}$ (Figure 7). Hopefully, results from Flow Cytometry analysis will be able to shed light on the cell size composition in the waters.

In two cases (21st December 03; ID 264371 and 6th January 2004: ID 264396), the water filtered through the Millipore filter (0.2μ) showed some orange-brownish colouration. As a result, although the sample (filtered through GF/F filter) was not coloured, the blanks became coloured because they were rinsed with the Millipore-filtered waters (Figure 8a). This completely altered the shapes and magnitudes of the spectra (blanks were much higher than the samples) resulting into completely negative absorption values (Figure 8b). We hypothesize that the smaller cells present in the water were probably delicate and did

burst during filtration, resulting in the observed colouration. This hypothesis could only be proved after analysis of HPLC and Flow Cytometry samples.

Coloured Dissolved Organic Matter (CDOM)

Given the oligotrophic Case 1 waters, we did not expect to find significant CDOM in the water. This was supported with the observed CDOM spectra; they were always low and close to the baseline. Sometimes most part of the CDOM spectrum was below the baseline. However, in the few cases where the chlorophyll concentration in the water was relatively high, the CDOM spectrum was much higher than the baseline.

Results from the Hyperspectral Radiometer (Ocean Optics)

In the first three days of sampling, we could not do Ocean Optics (OO) measurements, although we could do those of Simbada (Simbada-21 data were not processed further). This is because the OO-Reader could not equilibrate around 20^0C, due to high ambient temperatures on deck. Finally, we had to come up with the ice solution (Andrew Forbes, Pers. Comm.), whereby we had to put the OO-Reader into the cool box, for 15-30 minutes before doing the measurements. This "trick" worked fine for Hyperspectral-Radiometer measurements for the rest of Leg 5 transect. Ocean Optics data were processed on board into daily Excel worksheets, and graphs were produced using the Microcal Origin Software.

Examples of the data obtained are given in Figures 9 and 10, which shows radiance for sea (L_M), sky (L_{SKY}) and spectralon (L_{spec}); downwelling (E_D) and water-leaving radiance (L_W) as well as the corresponding remote sensing reflectance (R_{RS}). Under normal conditions, i.e., few clouds or clear sky, we expect to get higher values of L_{spec} than those of L_{SKY}; and in turn the L_{SKY} values higher than L_M values (e.g., Figure 9a). However, when the condition is total overcast, there is a "glare" from the sky, and the results show a different trend, whereby the $L_{SKY} >> L_{spec}$ (see Figure 10a). For the data shown in Figure 10, taken on 17th January 2004, there was and intense "glare" on the sky such that we only needed an integration time of 10 msec to do sky measurements. Details of OO results for other days of the cruise are explained elsewhere (Pru Bonham's report).

ACKNOWLEDGEMENT

This cruise was a very unique opportunity for me! I am happy and proud that I got a golden chance to attend such a prestigious BEAGLE 2003 Expedition. I would like to begin by thanking my sponsors: The Partnership for Observation of the Global Oceans (POGO) and International Ocean Colour Coordinating Group (IOCCG) for enabling me to attend this wonderful Expedition. My special gratitude goes to Drs. Shubha Sathyendranath and Trevor Platt for making it possible. I am grateful to the Chief Academic Officer, University of Dar es Salaam, Prof. M.H.H. Nkunya, and the Director of the Institute of Marine Sciences, Dr. A.M. Dubi, for granting me permission to attend the cruise.

I would like to thank the JAMSTEC Staff, especially Prof. Masao Fukasawa (Chief Scientist) for overall support. Thanks to Dr. Takeshi Kawano, Satoshi Ozawa, Hiroshi

Matsunaga, and Hirofumi Yamamoto for their support, cooperation and a well-organized sampling Programme. The bucket team did a great job! Thanks to: Teppei Kurowaka, Miki Kawazoe, Tomomi Watanabe and Ayumi Shioya. I am also grateful to Kenichiro Sato (Noli) for all his help, especially providing me with sampling outfits. Ms. Pru Bonham, the Bio-optical Specialist for Leg 5, was a delight to work with! She created a conducive working environment, and we worked as a good team…. Thank you so much Pru for everything. It was also nice working with Benjamin Wigley (my co-trainee). I am grateful to the help provided by other participants of the cruise, to our bio-optical group: thank you Jean Mwicigi, Antonio Mubango and John Bemiasa.

We are very grateful to Dr. Andrew Forbes for all his help with solar light, data backup and processing the absorption data. Special thanks goes to Vivian Lutz: she gave us a quick training and tips on bio-optical measurements, gave us her Fortran programs for processing absorption data as well as short-cut notes to all the protocols. This made our life easier in the bio-lab. I am grateful to Venetia Stuart and Tony Payzant, for their efficient communication, and always being quick to respond to my numerous queries. My heartfelt gratitude goes to the entire sampling and technical team of JAMSTEC & MWJ for their friendship and support; to the Captain, Akamine Masaharu, and Officers of the RV Mirai; all Crew Members and Caterers for working so hard on a day-to-day basis to make sure that life ran smoothly onboard.

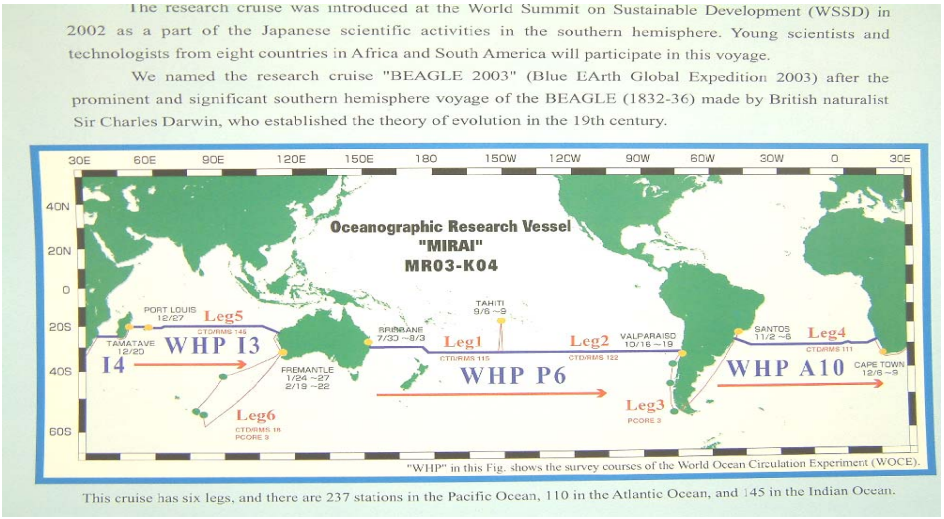


Figure 1: Showing the cruise tracks for the BEAGLE Expedition. Note that Leg5 covers from Cape Town, South Africa to Fremantle, Australia. This leg was conducted from 9th December 2003 to 24th January 2004.

Figure 2: Showing the Conductivity Temperature Density (CTD) device. The CTD was used to collect water samples at pre-determined depths, for different analyses.

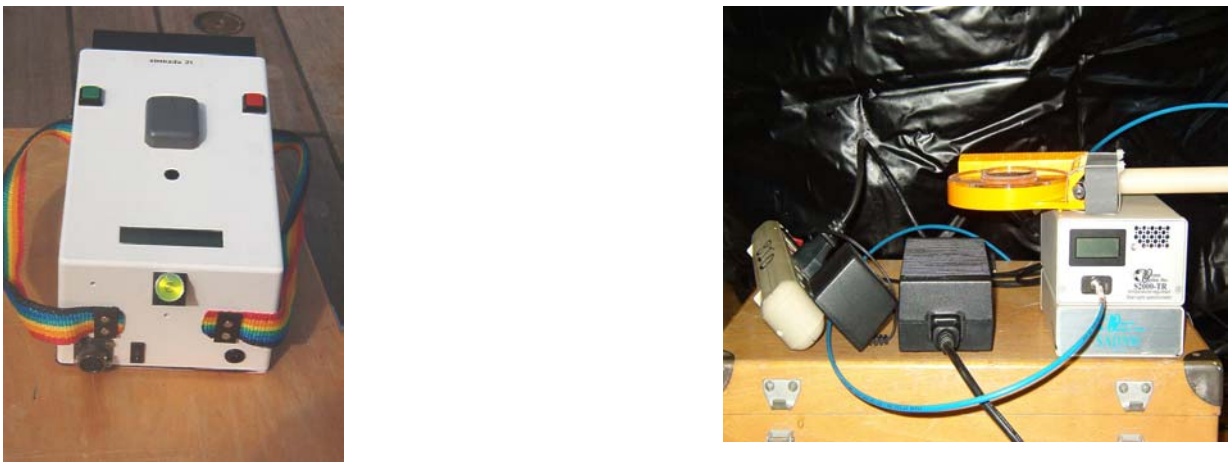


Figure 3: showing equipment used for solar light measurements: the Simbada-21 (left-hand side) and the Hyperspectral radiometer on the right (*reproduced from Brian Irwin's talk*).

Figure 4: Contrast between a) oligotrophic ocean (blue colour, on the left photo) and b) waters with relatively high content of chlorophyll concentration (the right-hand photo)

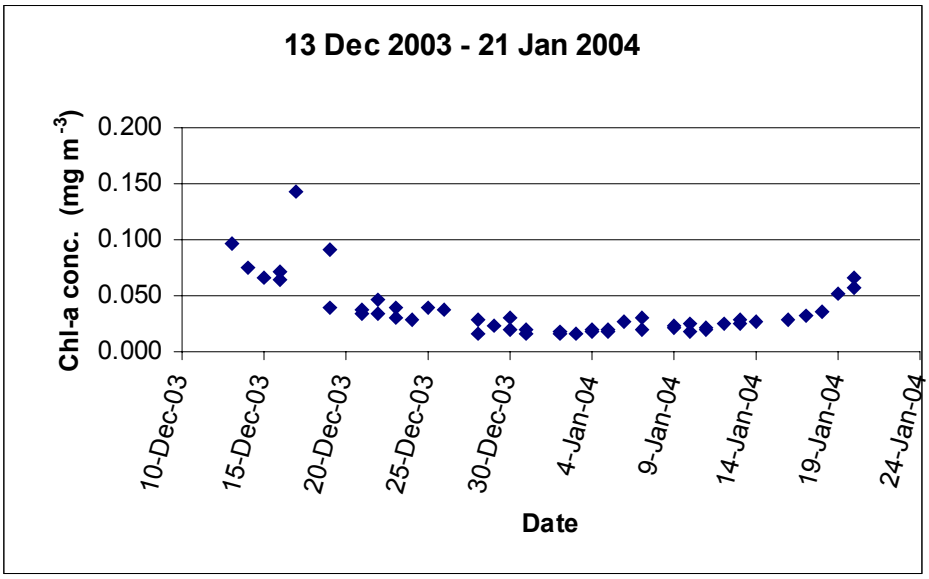


Figure 5: Showing surface chlorophyll-*a* concentration for the entire sampling time for Leg 5. Please note the low values of chl-*a* for most of the cruise time, especially in blue oceanic waters. For waters close to the coasts (South Africa, Madagascar and Australia), the values were slightly high, above 0.05 mg m^{-3}

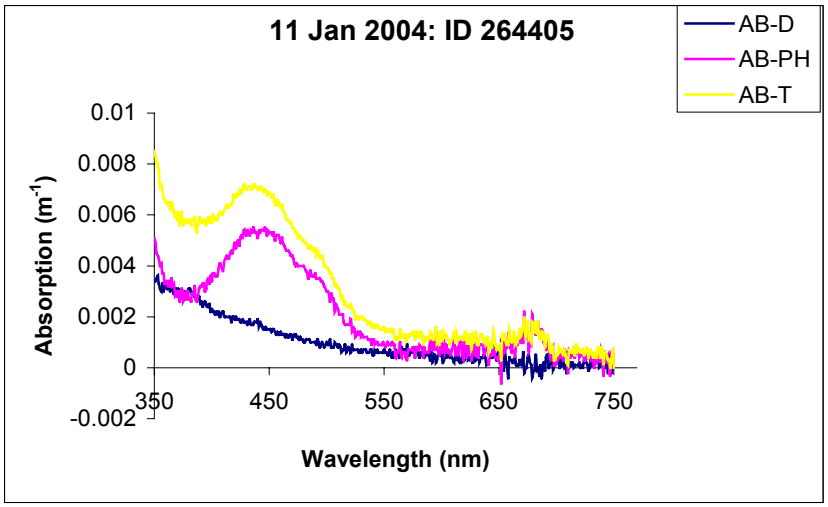


Figure 6a: Showing absorption spectra for total particulate (AB-T); phytoplankton (AB-PH) and detrital material (AB-D) for 11th January 2004 sample. Each spectrum is an average of ten measurements. The spectra are noisy because of very low chl-*a* concentration in the water.

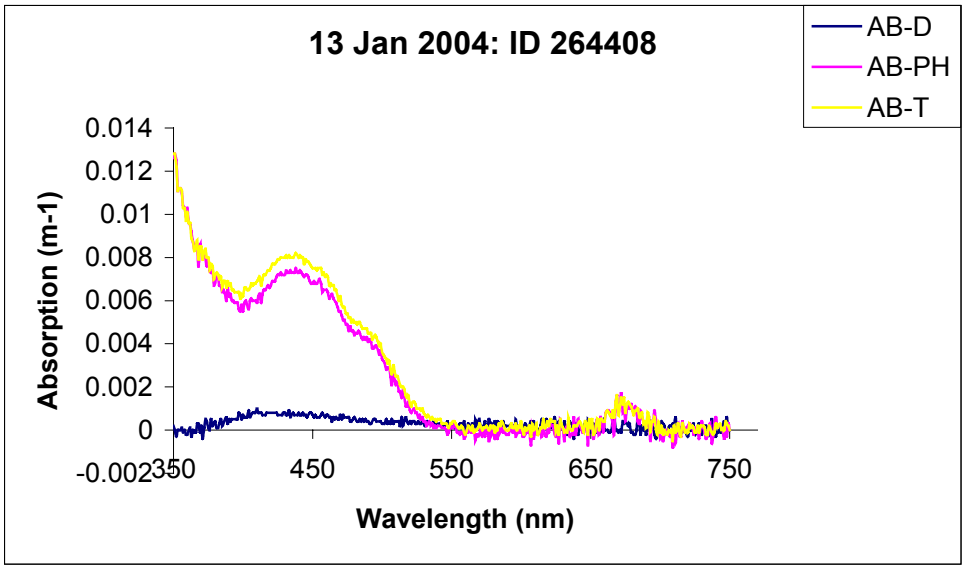


Figure 6b: Similar to Fig. 6a, but for 13th January 2004. Note the similarity in the shape and closeness in the magnitudes for the total particulate and phytoplankton absorption spectra, suggesting that absorption by particulate materials in the water was dominated by phytoplankton = case 1 waters.

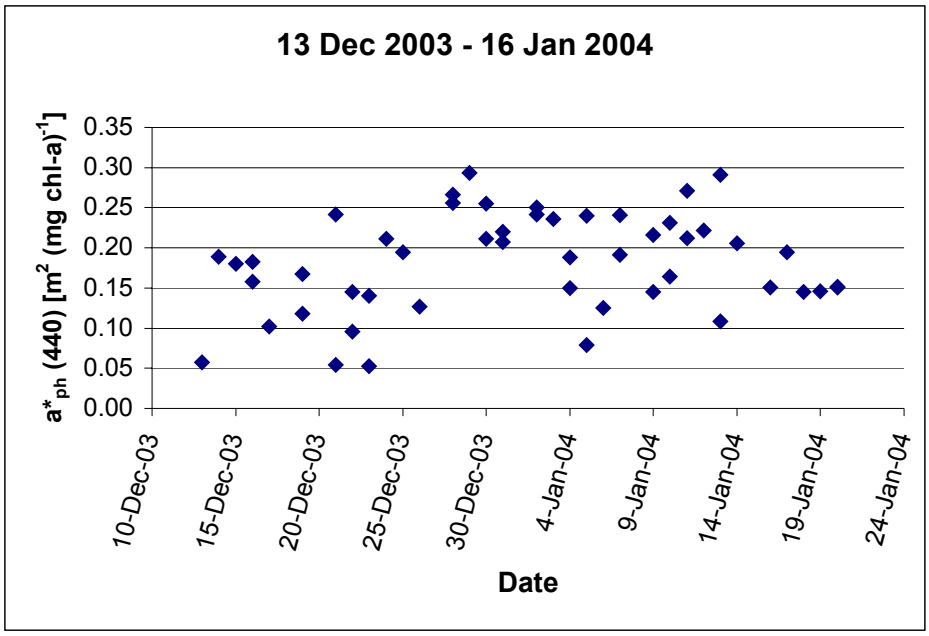


Figure 7: Showing specific absorption coefficient of phytoplankton at 440 nm (a^*_{ph} (440)), for the entire data set (50 values) of Leg 5. The high values of a^*_{ph} (440), implies existence of small phytoplankton cells in the waters.

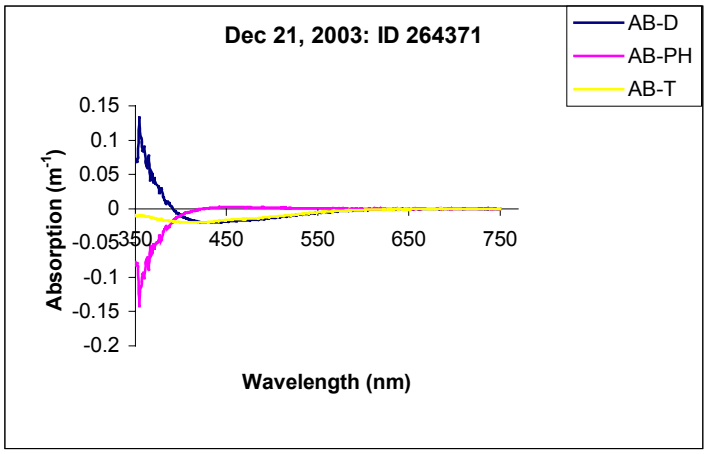


Figure 8: a) Left side: showing the coloured GF/F filters for 21st Dec. 03 and 6th Jan. 04. The colouration was obtained after rinsing with waters filtered through the 0.2µ Millipore filter. b) Right side: depicts the corresponding absorption spectra for 21st December 2003

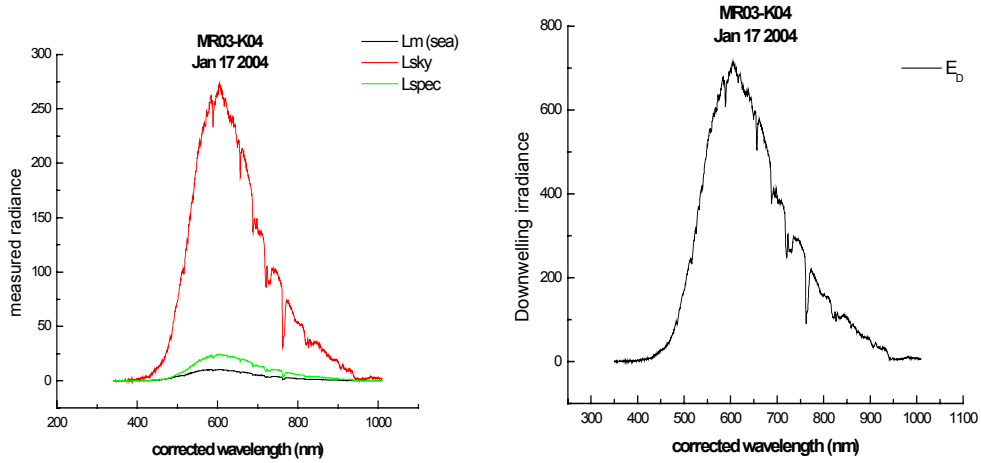
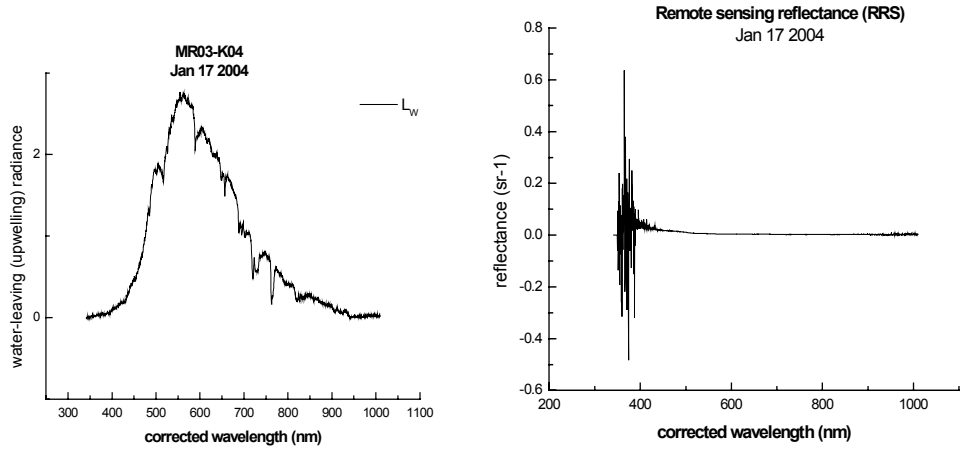


Figure 9: Examples of OO files from a day with heavy overcast, January 17 2004
a) Left: Measured radiances from sea, sky and spectralon (note how high L_{SKY} is)
b) Right: Downwelling radiance measured with the spectralon



c) Left: Water leaving radiance L_W
d) Right: Remote sensing reflectance R_{RS}

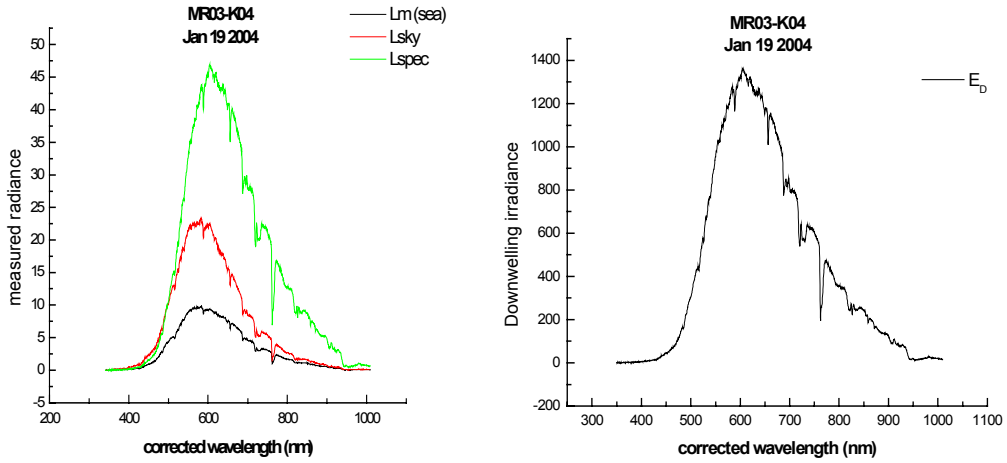
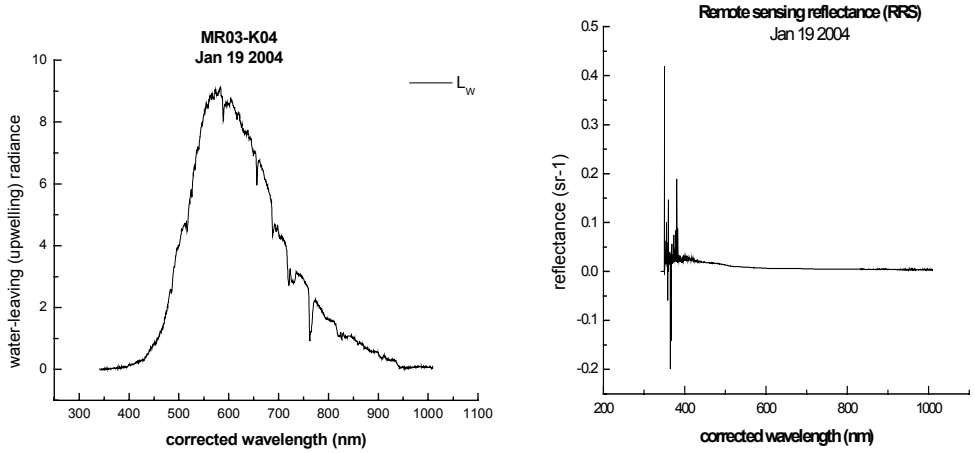


Figure 10: Examples of Ocean Optics files from a sunny day, January 19 2004
a) Left: Measured radiances from sea, sky and spectralon (L_{SKY} is lower than S_{spec})
b) Right: Downwelling radiance measured with the spectralon



c) Left: Water leaving radiance L_W
d)Right: Remote sensing reflectance R_{RS}